Survey of HSPF and Heating Capacity Ratings for ICM Mixed Systems Relative to OEM Mixed Systems and Highest Sales Volume Tested Combinations

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INTRODUCTION

This investigation compares the Heating Seasonal Performance Factor (HSPF) and the high temperature heating capacity (Q(47)) ratings of Independent Coil Manufacturers (ICMs) and Original Equipment Manufacturers (OEMs) to determine the distribution of mixed system ratings provided by ICMs and OEMs. ICMs match their indoor coil/air handlers with outdoor units from several OEMs. If not laboratory tested as a complete system, these “mixed” combinations must be rated using a procedure based upon sound engineering concepts and approved by the United States Department of Energy (CFR 2006). This investigation takes the ratings published by the ICMs for their mixed systems and compares them to the HSPF and Q(47) ratings of the OEM outdoor unit/indoor unit Highest Sales Volume Tested Combinations (HSVTC) or matched systems. The ratings are compared by looking at the percentage of units with ratings that are higher, equal, and lower than the HSVTC. The percentages are calculated by taking the number of units occurring in each category and dividing by the total number of units in the survey.

This survey examines the existing Air Conditioning and Refrigeration Institute’s directory of unitary equipment (ARI 2006b). Only mixed systems with an active status and systems with the same ARI-type of indoor unit are compared; therefore, coil-only mixed systems are compared to coil-only HSVTCs and coil-blower mixed systems are only compared to coil-blower HSVTCs.

ICMs SURVEYED

Table 1 presents the thirteen ICMs currently listed in the ARI Unitary Directory of Certified Performance for heat pumps and heat pump coils (ARI 2006b) along with the number of active listings as of November 2006. Only six ICMs were included in this survey, and seven were excluded. Space Pak and Unico were not included in the survey because they manufactured high velocity indoor airflow systems which use indoor air-handler types not tested by the OEMs. Benchmark was also not included because this company had only two active systems, and they could not be matched to a same indoor coil type HSVTC. Others were excluded because they had no active listings.

Table 1: Indoor coil manufacturers surveyed

Indoor Coil Manufacturer	# of Active Listings	Indoor Coil Manufacturer	# of Active Listings
Advanced Distributor Products	2 378	Allstyle Coil Co. Inc.	0
Aspen Manufacturing	562	Benchmark Manufacturing, Inc.	2
Eubank Manufacturing Enterprises, Inc.	30	Firm Group Co., Ltd.	0
Freedom Air	219	Haier America	0
Heat Controller, Inc.	0	Space Pak	572
Summit Manufacturing, Inc.	812	Superior Coils, Inc.	7 096
Unico, Inc.	61		
Total # of Active Listings: 11 732 Highlighted manufacturers are included in the survey.			

SUMMARY STATISTICS

Mixed System HSPF Ratings

Table 2 is the list of ICM coil-only mixed systems showing the percentage of systems rated by that ICM which were higher, equal, or lower than the matched HSVTC. Figure 1 graphically shows the same information as listed in Table 2; each ICM is represented by three columns in the figure. The columns represent the percentage of ICM mixed systems that were rated higher, equal, or lower than the OEM HSVTC. The percentage of systems rated higher, equal, or lower than the HSVTC for all ICMs combined is also represented.

Of all the coil-only mixed systems surveyed, 10.1 % of mixed systems were rated higher than the HSVTC. This is the percentage of systems rated higher than the HSVTC for all of the ICMS who rated coil-only systems. One ICM exceeds this value; ICM H, also shown in Figure 1, ranks 59.4 % of their coil-only mixed systems higher than the matched OEM HSVTC. The number of units ranked higher than the OEM matched systems is a small percentage of the total units manufactured.

Table 2: ICM Coil-Only HSPF ratings relative to the HSVTC ratings

Indoor Coil Manufacturer	% Higher	% Equal	% Lower
ICM A	0.0	100.0	0.0
ICM C	1.7	3.3	95.0
ICM F	4.9	9.9	85.2
ICM H	59.4	2.9	37.7
ICM J	2.4	94.0	3.6
*All ICMs	10.1	48.4	41.5

* All calculated from number of units in a category divided by the total number of units.

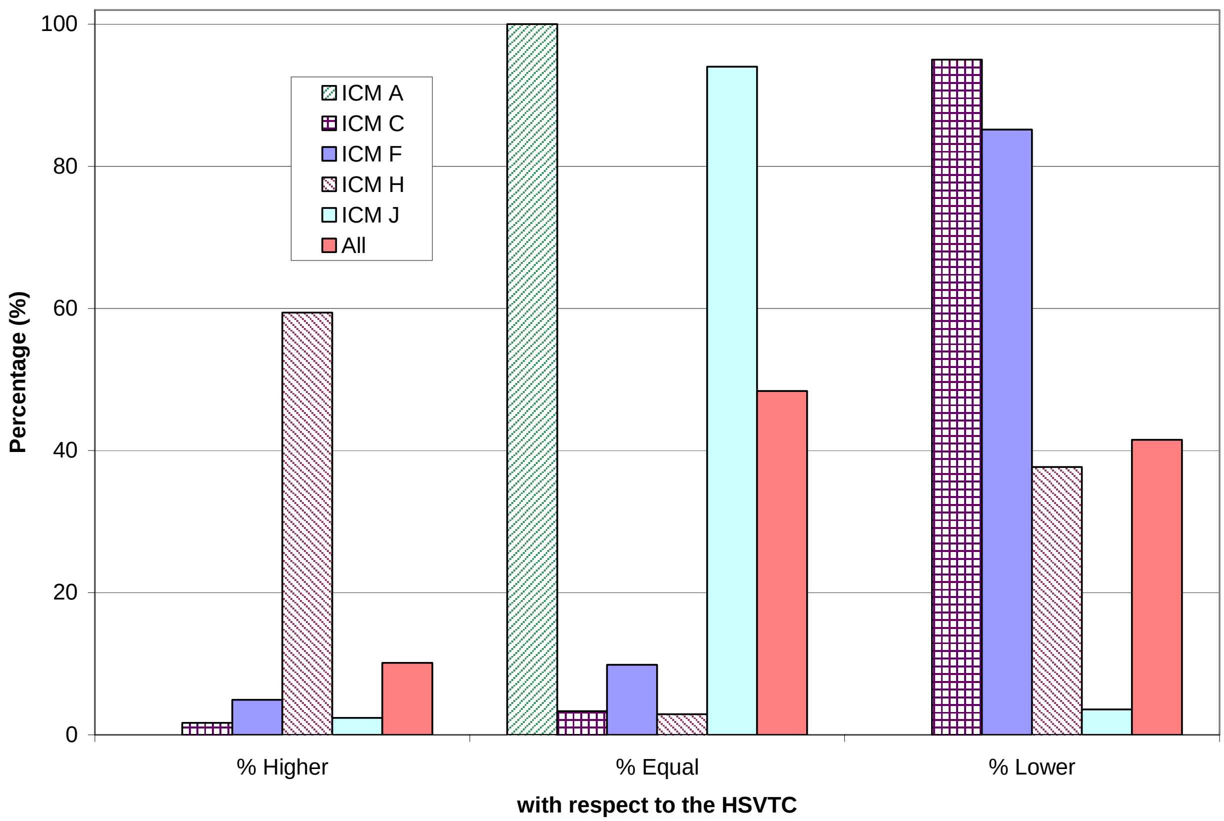

Figure 1: ICM Coil-Only HSPF ratings % Higher, % Equal, and % Lower than the HSVTC (Each ICM is represented by three bars; one for each category.)

Table 3 summarizes the survey results for HSPF ratings of mixed coil-blower systems. Again the comparison was made based upon the percentage of mixed systems that were rated higher, equal, and lower than the matched HSVTC. Figure 2 graphically represents this information with three bars for each ICM; one bar above the three categories.

Table 3: ICM Coil-Blower HSPF ratings relative to the HSVTC ratings

Indoor Coil Manufacturer	% Higher	% Equal	% Lower
ICM A	0.0	100.0	0.0
ICM C	6.5	1.4	92.1
ICM F	3.2	34.0	62.8
ICM H	27.2	27.2	45.6
ICM J	0.0	52.0	48.0
ICM K	0.0	31.6	68.4
*All	6.3	9.2	84.5

* All calculated from number of units in a category divided by the total number of units.

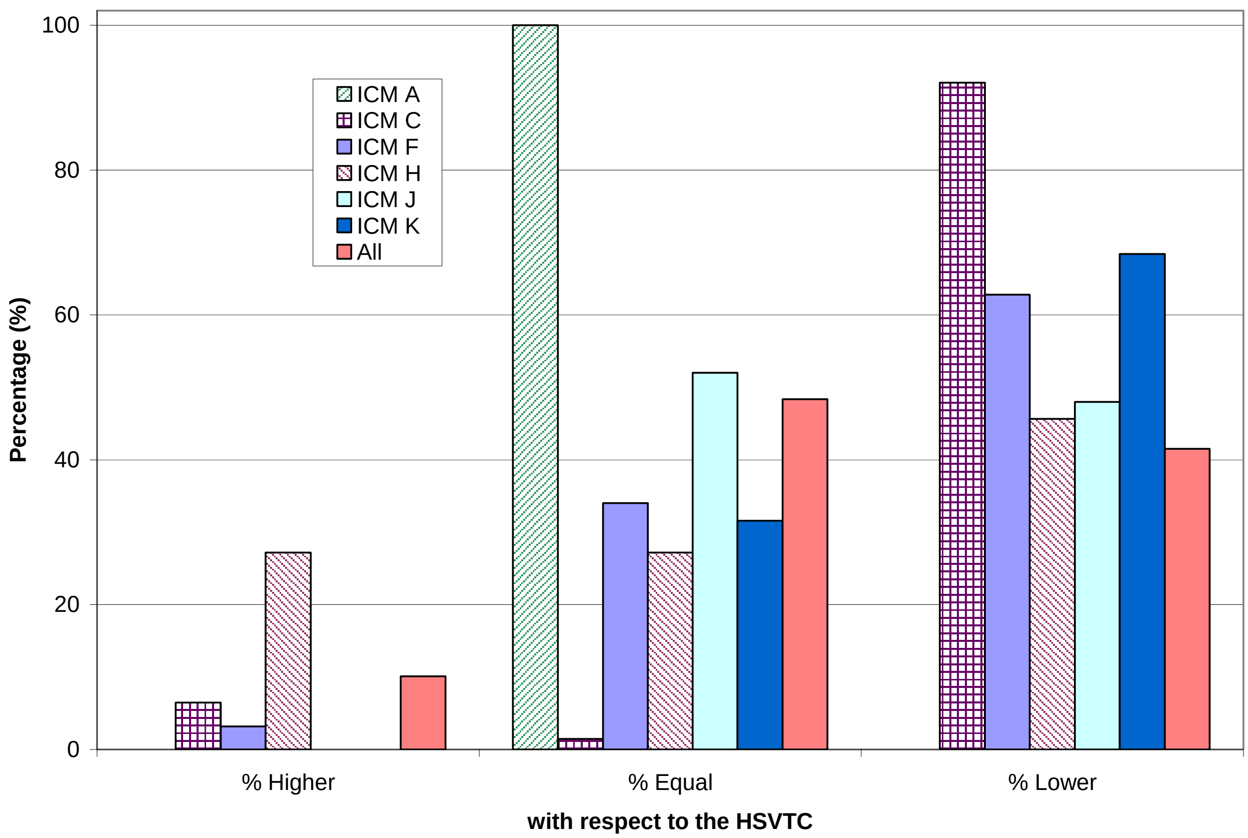

Figure 2: ICM Coil-Blower HSPF ratings % Higher, % Equal, and % Lower than the HSVTC (Each ICM is represented by three bars; one for each category.)

For the mixed coil-blower systems, the percentage of ICMs rating higher than the HSVTC was 6.3 %. ICM H and ICM C, also shown in Figure 2, rated 27.2 % and 6.5 %, respectively, of their mixed systems higher than the HSVTC. As shown in Figure 2, the percentages of units rated higher than the OEM matched systems is a small percentage of the total number of units rated.

Mixed System Q(47) Ratings

Table 4 lists the heating capacity rating percentages that were higher, equal, or lower than the OEM HSVTC for coil-only mixed systems. The percentages of mixed systems higher, equal, or lower than the OEM HSVTC are also included in Table 4. Figure 3 graphically represents this information with three columns for each ICM; each column represents the percentage of mixed systems higher, equal, or lower than the HSVTC. The values for each category are represented by three columns above the appropriate category.

The percentage of mixed coil-only systems with *Q*(47) ratings higher than the OEM HSVTC is 1.4 %. ICM H, also shown in Figure 3, rated 10.1 % of their coil-only mixed systems higher than the OEM HSVTC.

Table 4: ICM coil-only Q(47) ratings relative to the HSVTC ratings

Indoor Coil Manufacturer	% Higher	% Equal	% Lower
ICM A	0.0	100.0	0.0
ICM C	0.0	0.0	100.0
ICM F	0.0	0.0	100.0
ICM H	10.1	85.5	4.3
ICM J	0.4	24.2	75.4
*All	1.4	23.6	74.9

* All calculated from number of units in a category divided by the total number of units.

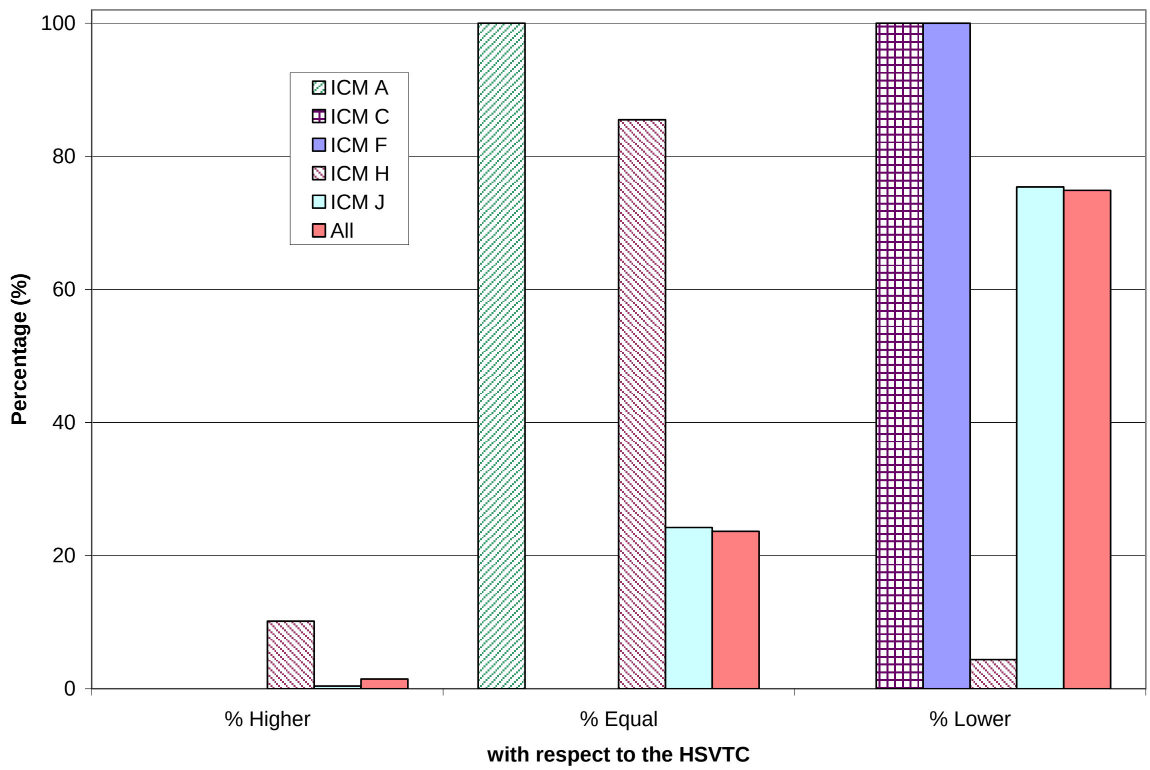

Figure 3: ICM Coil-Only Q(47) ratings % Higher, % Equal, and % Lower than the HSVTC (Each ICM is represented by three bars; one for each category)

Table 5 summarizes the Q(47) survey results for coil-blower mixed systems and Figure 4 presents these results graphically. Of the 7 642 mixed systems in this survey, 3.1 % were rated higher than the OEM HSVTC. Of the six ICMs in the survey, three exceeded the percentage of units rated higher than the HSVTC; they were ICM H, ICM J, and ICM K, also shown in Figure 4, with 42.1 %, 36.0 %, and 68.4 %, respectively.

Table 5: ICM Coil-Blower Q(47) ratings relative to the HSVTC ratings

Indoor Coil Manufacturer	% Higher	% Equal	% Lower
ICM A	0.0	100.0	0.0
ICM C	1.4	1.7	96.9
ICM F	3.1	6.8	90.1
ICM H	42.1	44.1	13.8
ICM J	36.0	12.0	52.0
ICM K	68.4	31.6	0.0
*All	3.1	4.1	92.8

* All calculated from number of units in a category divided by the total number of units.

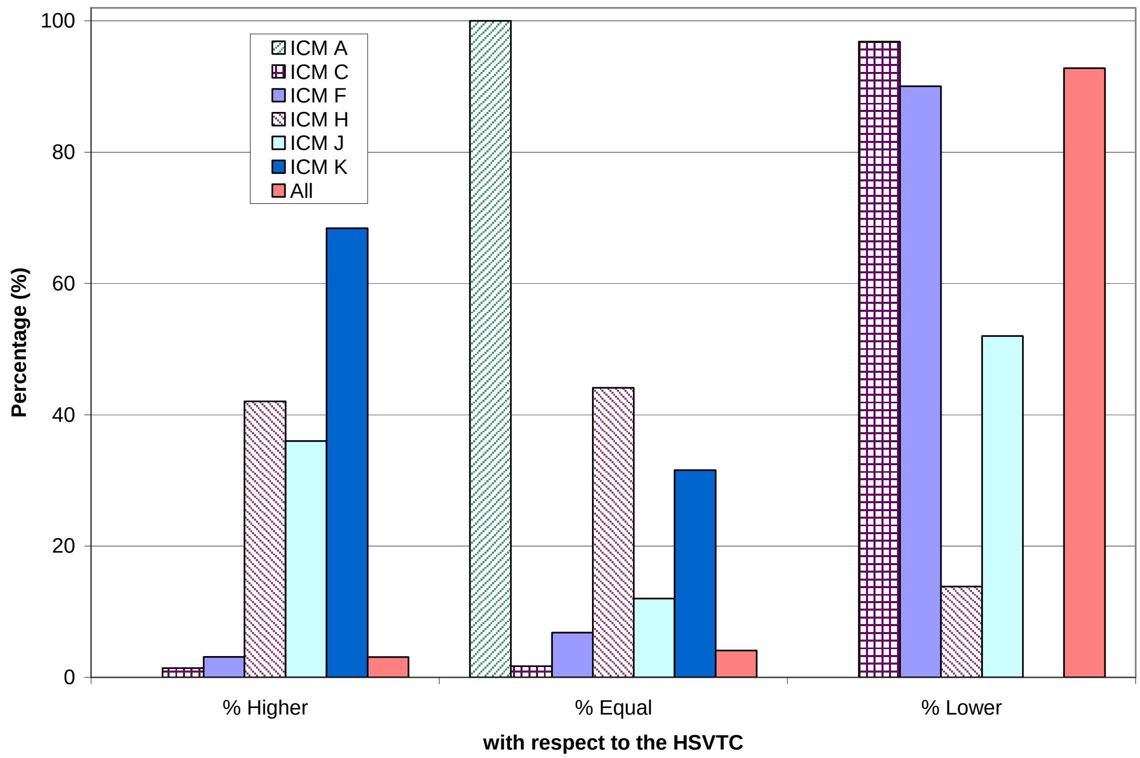

Figure 4: ICM Coil-Blower Q(47) ratings % Higher, % Equal, and % Lower than the HSVTC (Each ICM is represented by three bars; one for each category.)

ICMs WITH THE LARGEST PERCENTAGE OF HIGH RATINGS

HSPF and Q(47) ratings for mixed systems may be determined by testing according to ARI Standard 210/240 (ARI 2006a) or by using an alternative rating method (ARM) approved by the U.S. Department of Energy (CFR 2006). One such ARM was presented by Domanski (1990). This method was developed from an analysis of existing heating data for mixed and matched systems. The mixed system's rated heating capacity was given by Equation 1.

$$Q_x(47) = \left[Q_m(47) - BP_{fm}\right] R_{co}^{\;0.22} + BP_{fx} \tag{1}$$

where: $Q_x(47)$ = mixed system rated heating capacity at ARI Standard 210/240 conditions [W or (Btu/h)]

$Q_m(47)$ = matched system rated heating capacity as certified by its manufacturer according to ARI standards [W or (Btu/h)]

R_{co} = heating capacity ratio of the mixed coil to the matched coil at ARI standard conditions without accounting for fan heat [W or (Btu/h)]. Mixed coil airflow rate is not to exceed 60.4 L/s per 1000 W (37.5 scfm per 1000 Btu/h) of rated capacity. If airflow rate information is not known for the matched coil, the indoor airflow rate is calculated using Equation 2.

R_{co}, must be a minimum of 0.85 and a maximum of 1.20 to apply this method.

B = conversion constant [1 W/W or 3.413 Btu/(W h)]

P_{fm} and P_{fx} = matched and mixed system fan power, respectively [W]

$$\dot{V}_m = \frac{C}{D} Q_m(95) \tag{2}$$

where: $\dot{V}_m$ = matched system indoor airflow rate (L/s (scfm))

$Q_m(95)$ = rated cooling capacity at ARI standard conditions (kW (Btu/h))

C = 57.031 L/(s kW) (425 scfm/ton)

D = 1 kW/kW (12 000 Btu/(h ton))

The HSPF of the mixed system was given by Domanski (1990) using Equation 3.

$$\mathrm{HSPF_x} = \mathrm{HSPF_m} \; \frac{1428\, R}{R^n + 0.141\,(F+1) + 0.146\, Z} \tag{3}$$

where: $\mathrm{HSPF_x}$ and $\mathrm{HSPF_m}$ = mixed and matched system rated HSPF

$R = Q_x(47)/Q_m(47)$

$Z = R$ for capillary/short tube heating mode expansion devices

Z = 1 for thermostatic expansion valve (TXV) heating mode expansion devices

$F = P_{fx} / P_{fm}$ or the ratio of mixed to matched indoor fan power

n = -0.31 for capillary/short tubes, -0.46 for a TXV

Equation 1 may be expanded and solved for the ratio $Q_x(47)/Q_m(47)$.

$$Q_x(47) = R_{co}^{\;0.22}\, Q_m(47) - B\, R_{co}^{\;0.22} P_{fm} + B\, P_{fx} \tag{4a}$$

Let the ratio $P_{fx}/P_{fm} = F$ and divide both sides of Equation 4a by $Q_m(47)$.

$$\frac{Q_x(47)}{Q_m(47)} = R_{co}^{\;0.22} - B\left(R_{co}^{\;0.22} - F\right)\frac{P_{fm}}{Q_m(47)} \tag{4b}$$

The power of the matched system indoor fan may be expressed using Equation 2 and the following conversion.

$$P_{fm} = u\dot{V}_m = u\, \frac{C}{D}\, Q_m(95) \tag{5}$$

where u = 0.773 W/(L/s) [0.365 W/scfm]

Substitution of Equation 5 into Equation 4b yields Equation 6 as an expression of the ratio of the mixed to matched rated heating capacity, $Q_x(47)/Q_m(47)$.

$$\frac{Q_x(47)}{Q_m(47)} = R_{co}{}^{0.22} - B\left(u\frac{C}{D}\right)\left(R_{co}{}^{0.22} - F\right)\frac{Q_m(95)}{Q_m(47)} \tag{6}$$

Equation 6 reveals the heating capacity ratio, $Q_x(47)/Q_m(47)$, as a function of three variables: $\frac{Q_x(47)}{Q_m(47)} = \mathrm{f}\left[R_{co}, F, \frac{Q_m(95)}{Q_m(47)}\right]$. In Domanski's procedure the coil-only mixed-matched capacity ratio, R_{co}, was limited to a range of 0.85 to 1.2. The indoor fan power ratio, F, scales in a one to one fashion with the capacity ratio, R_{co}, for coil-only systems where the fan power is calculated based upon airflow rate. This directly proportional relationship ($R_{co} = F$) in fan power ratio may not hold for coil-blower systems due to variations in fan efficiency or air-mover design between mixed and matched systems.

A survey of the HSVTC listings for all of the matched systems used by the ICMs was performed to determine the range of values for $Q_m(95)/Q_m(47)$ used in Equation 6. Table 6 shows that the cooling capacity to heating capacity ratio, $Q_m(95)/Q_m(47)$, for these OEM's HSVTCs had a minimum of 0.9000 and 0.7754 for coil-only and coil-blower systems, respectively. The maximum value was 1.0714 and 1.2268 for coil-only and coil-blower systems, respectively. Using this range of capacity ratios and previously specified ranges on R_{co} and F, Table 7 shows the range of mixed to matched system heating capacity ratios, $Q_x(47)/Q_m(47)$, as calculated using Equation 6.

According to this calculation, for coil-only mixed systems, the heating capacity ratio $Q_x(47)/Q_m(47)$ varied from a minimum of 0.9594 to a maximum of 1.0484. The same calculation was performed for coil-blower systems, but the $F = R_{co}$ relationship may not hold for coil-blower systems due to differing fan efficiencies or air-mover designs. With this fact in mind, the calculation shows that coil-blower mixed system heating capacity ratios, $Q_x(47)/Q_m(47)$, varied from a minimum of 0.9587 to a maximum of 1.0495. Using the above calculations shows that coil-only and coil-blower mixed rated heating capacity ratio, $Q_x(47)/Q_m(47)$, fell within a range of 0.95 to 1.05.

With bounds established for the mixed-matched heating capacity ratio, $Q_x(47)/Q_m(47)$, Equation 3 may be used to place bounds upon the mixed-matched HSPF ratio, $HSPF_x/HSPF_m$. Table 8 shows the resulting calculation of $HSPF_x/HSPF_m$ for coil-only and coil-blower systems derived from information in Table 7. There is only a slight difference between coil-only and coil-blower $HSPF_x/HSPF_m$ even for TXV and capillary/short tube equipped systems; the $HSPF_x/HSPF_m$ ratio ranges from 0.93 to 1.08.

Table 6: HSVTC ratio of rated cooling capacity, $Q_m(95)$, to rated heating capacity, $Q_m(47)$, for all matched system manufacturers used by the mixed systems in this survey (For each manufacturer, the first row entry is for coil-only and the second row entry is for coil-blower systems.)

HSVTC	min	max	avg	st dev	HSVTC	min	max	avg	st dev
AIRE-FLO	NA	NA	NA	NA	HEAT CONTROLLER, INC.	NA	NA	NA	NA
	0.9681	1.1215	1.0207	0.0332		0.9474	1.1442	1.0268	0.0422
AIRPRO, UNITARY PRODUCTS GROUP	0.9829	1.0222	1.0026	0.0197	HEIL	NA	NA	NA	NA
	0.9474	1.0000	0.9811	0.0210		0.8947	1.0870	0.9794	0.0323
AIRQUEST	NA	NA	NA	NA	INTERTHERM	0.9892	1.0714	1.0191	0.0232
	0.8947	1.0870	0.9753	0.0341		0.9500	1.1081	1.0123	0.0403
AMANA HEATING AND AIR CONDITIONING	0.9735	0.9735	0.9735	0.0000	KEEPRITE	NA	NA	NA	NA
	0.9255	1.0909	1.0066	0.0353		0.8947	1.0870	0.9765	0.0352
AMERICAN STANDARD, INC.	NA	NA	NA	NA	KELVINATOR	0.9892	1.0714	1.0190	0.0229
	0.7754	1.2000	1.0662	0.0505		0.9500	1.1081	1.0162	0.0393
ARCOAIRE	NA	NA	NA	NA	KENMORE	0.9161	1.0222	0.9790	0.0337
	0.8947	1.0870	0.9765	0.0352		0.8947	1.0870	0.9763	0.0346
ARMSTRONG AIR CONDITIONING, INC.	0.9091	1.0435	0.9705	0.0338	LENNOX INDUSTRIES, INC.	NA	NA	NA	NA
	0.9111	1.1215	1.0101	0.0503		0.9530	1.1705	1.0489	0.0476
BROAN	0.9892	1.0714	1.0191	0.0240	LUXAIRE, UNITARY PRODUCTS	0.9000	1.0222	0.9703	0.0319
	0.9500	1.1081	1.0098	0.0384		0.9530	1.1705	1.0489	0.0476
BRYANT HEATING AND COOLING SYSTEMS	0.9417	1.0000	0.9709	0.0172	MAYTAG	0.9892	1.0714	1.0198	0.0242
	0.9182	1.2268	0.9854	0.0303		0.9459	1.1081	0.9977	0.0344
CARRIER AIR CONDITIONING	NA	NA	NA	NA	MILLER	0.9892	1.0714	1.0192	0.0240
	0.9182	1.2268	0.9788	0.0412		0.9500	1.1081	1.0115	0.0419
COLEMAN, UNITARY PRODUCTS	0.9000	1.0222	0.9703	0.0319	NORDYNE, INC.	0.9892	1.0714	1.0190	0.0232
	0.9351	1.0727	0.9819	0.0268		0.9459	1.1081	1.0071	0.0378
COMFORTMAKER	NA	NA	NA	NA	PHILCO	0.9892	1.0714	1.0190	0.0229
	0.8947	1.0870	0.9765	0.0352		0.9500	1.1081	1.0162	0.0393
CONCORD	0.9423	1.0435	0.9861	0.0322	RHEEM MANUFACTURING COMPANY	0.9020	1.0641	0.9721	0.0394
	1.0116	1.1215	1.0456	0.0350		0.8941	1.1442	1.0192	0.0557
DUCANE	NA	NA	NA	NA	RUUD AIR CONDITIONING DIVISION	0.9020	1.0641	0.9718	0.0404
	0.9681	1.1215	1.0207	0.0332		0.8941	1.1442	1.0065	0.0554
ELECT-AIRE	0.9892	1.0714	1.0192	0.0240	TAPPAN	0.9892	1.0714	1.0179	0.0223
	0.9500	1.0714	0.9989	0.0378		0.9459	1.1081	1.0029	0.0387
EVCON, UNITARY PRODUCTS GROUP	0.9161	1.0087	0.9682	0.0291	TEMPSTAR	NA	NA	NA	NA
	0.9474	1.0000	0.9792	0.0211		0.8947	1.0870	0.9766	0.0350
FRASER - JOHNSTON, UNITARY	0.9161	1.0222	0.9790	0.0337	THE TRANE COMPANY	NA	NA	NA	NA
	0.9351	1.0000	0.9790	0.0238		0.7754	1.2000	1.0644	0.0546
FRIGIDAIRE	0.9892	1.0714	1.0179	0.0223	UNITED REFRIGERATION, INC.	0.9885	1.0222	1.0091	0.0181
	0.9459	1.1081	1.0029	0.0387		NA	NA	NA	NA
GIBSON	0.9892	1.0714	1.0182	0.0220	WESTINGHOUSE	0.9892	1.0714	1.0190	0.0232
	0.9500	1.1081	1.0097	0.0375		0.9459	1.1081	1.0029	0.0387
GOODMAN MANUFACTURING CO., LP.	NA	NA	NA	NA	WHIRLPOOL	0.9339	1.0556	0.9864	0.0305
	0.9580	1.0938	1.0075	0.0318		0.9333	1.1215	1.0023	0.0478
GRANDAIRE	0.9333	1.0714	1.0148	0.0280	XENON	0.9483	1.0071	0.9795	0.0173
	0.9500	1.1081	1.0181	0.0399		0.9426	1.1111	0.9997	0.0415
GUARDIAN, UNITARY PRODUCTS	0.9161	1.0087	0.9656	0.0335	YORK, UNITARY PRODUCTS GROUP	0.9000	1.0222	0.9717	0.0302
	NA	NA	NA	NA		0.9351	1.1111	0.9874	0.0318

Table 7: Mixed to matched heating capacity ratios calculated using Equation 6

Indoor Unit Type	R_{co}	$F = R_{co}$	$\frac{Q_m(95)}{Q_m(47)}$	$\frac{Q_x(47)}{Q_m(47)}$
Coil-Only	0.85	0.85	1.071	0.959
	1.20	1.20	1.071	1.048
Coil-Blower[1]	0.85	0.85	1.227	0.959
	1.20	1.20	1.227	1.050

1) $F = R_{co}$ may not hold for coil-blower indoor units with different indoor fan efficiencies or different air-movers.

Table 8: Mixed to matched HSPF ratios calculated using Equation 3 and Table 7

Indoor Unit Type	$\frac{Q_x(47)}{Q_m(47)} = R$	n	Z	F	$\frac{\text{HSPF}_x}{\text{HSPF}_m}$
Coil-Only	0.959	-0.31 (cap/short tube)	1.000	1.20	0.933
	1.048	-0.31 (cap/short tube)	1.000	0.85	1.076
	0.959	-0.46 (TXV)	1.000	1.20	0.929
	1.048	-0.46 (TXV)	1.000	0.85	1.081
Coil-Blower[1]	0.959	-0.31 (cap/short tube)	1.000	1.20	0.932
	1.050	-0.31 (cap/short tube)	1.000	0.85	1.077
	0.959	-0.46 (TXV)	1.000	1.20	0.927
	1.050	-0.46 (TXV)	1.000	0.85	1.082

1) $F = R_{co}$ may not hold for coil-blower indoor units with different indoor fan efficiencies or different air-movers.

MIXED SYSTEM RATINGS VERSUS ESTIMATED LIMITS

HSPF Ratings for Coil-Only Mixed Systems

Table 2 shows that ICM H lists 59.4 % of their coil-only mixed systems as having a higher HSPF than the matched HSVTC. This is higher than the survey total of 10.1 %. As shown in Figure 1, ICM H rates a small percentage of the total number of coil-only systems in this survey; therefore this is a small number of systems that are over-rated. Figure 5 shows the distribution of ICM H's mix-match HSPF ratio. The figure shows several systems above 1.08 which Table 8 lists as the maximum value.

Looking at the ARI database, ICM H lists one system with an HSPF ratio of 1.12. If we examine all of the OEM mixed systems for this outdoor unit, the HSPF ratio has a value of 1.00 for all twelve of the OEM systems that use this outdoor unit. All of the ratios above 1.08 occurring in Figure 5 are based upon this particular outdoor unit which has a HSPF ratio of 1.00 for the OEM mixed systems.

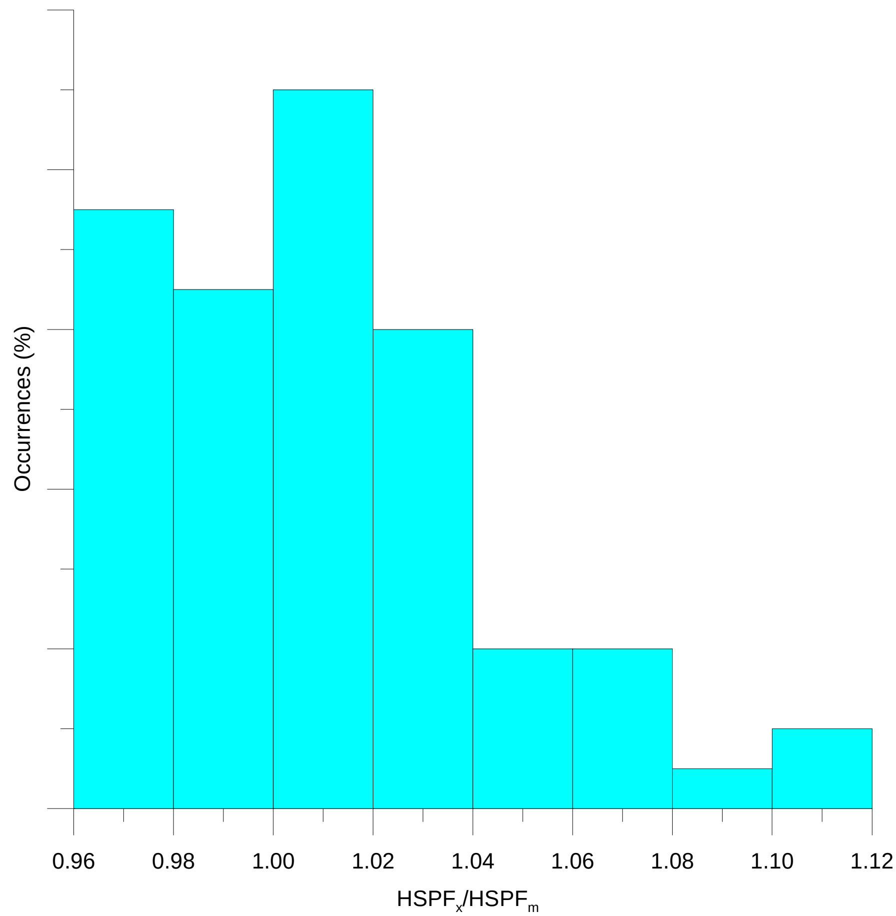

Figure 5: ICM H coil-only HSPF ratio, $HSPF_x/HSPF_m$, distribution

HSPF Ratings for Coil-Blower Mixed Systems

Table 3 shows that ICM C and ICM H list 6.5 % and 27.2 % of their mixed systems higher than the matched HSVTC. This is higher than the survey total of 6.3 %. Examining the percentage of coil-blower systems manufactured by ICM C and ICM H as shown in Figure 2 shows that the over-rated systems would comprise less than 10 % of the total systems surveyed. Figures 8 and 9 show the distribution of coil-blower HSPF ratios for ICM C and ICM H, respectively. Only ICM H had coil-blower HSPF ratios greater than 1.08.

Figure 7 shows that ICM H had several mixed systems with an HSPF ratio of 1.14. Using the ARI database, twenty-seven OEM coil-blower systems were found that used this outdoor unit, and these had a maximum HSPF ratio of 1.06. Looking at another ICM H mixed system with an HSPF ratio of 1.14, seven OEM mixed systems were found, and these had a maximum HSPF ratio of 1.06. ICM H exceeded the OEM mixed system HSPF ratings for all of their mixed systems rated with an HSPF ratio of 1.14.

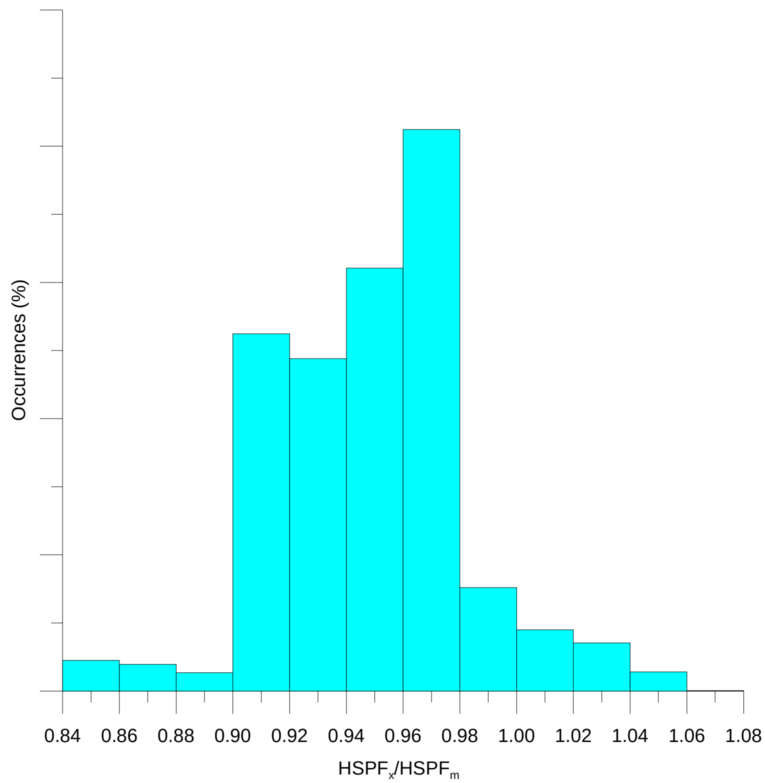

Figure 6: ICM C coil-blower HSPF ratio, $HSPF_x/HSPF_m$, distribution

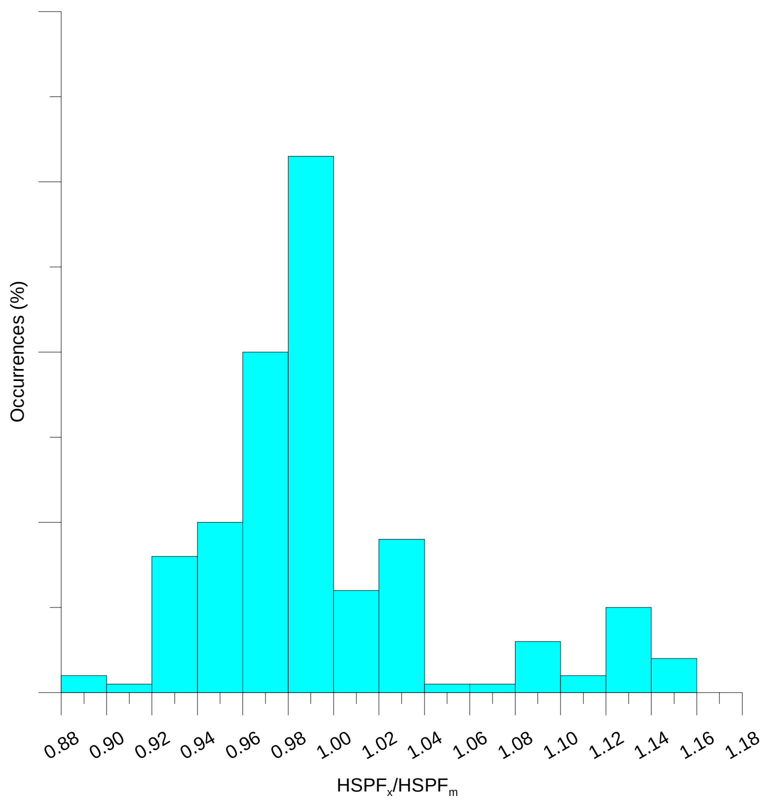

Figure 7: ICM H coil-blower HSPF ratio, $HSPF_x/HSPF_m$, distribution

Heating Capacity Ratings for Coil-Only Mixed Systems

Table 4 shows that ICM H lists 10.1 % of their mixed systems as having a higher coil-only $Q(47)$ than the HSVTC. This is higher than the survey percentage of 1.4 % of coil-only mixed systems with a rated $Q(47)$ higher than the HSVTC. Figure 8 shows the coil-only mix-match $Q(47)$ ratio distribution for ICM H. One mixed system had a heating capacity ratio greater than the calculated maximum of 1.05.

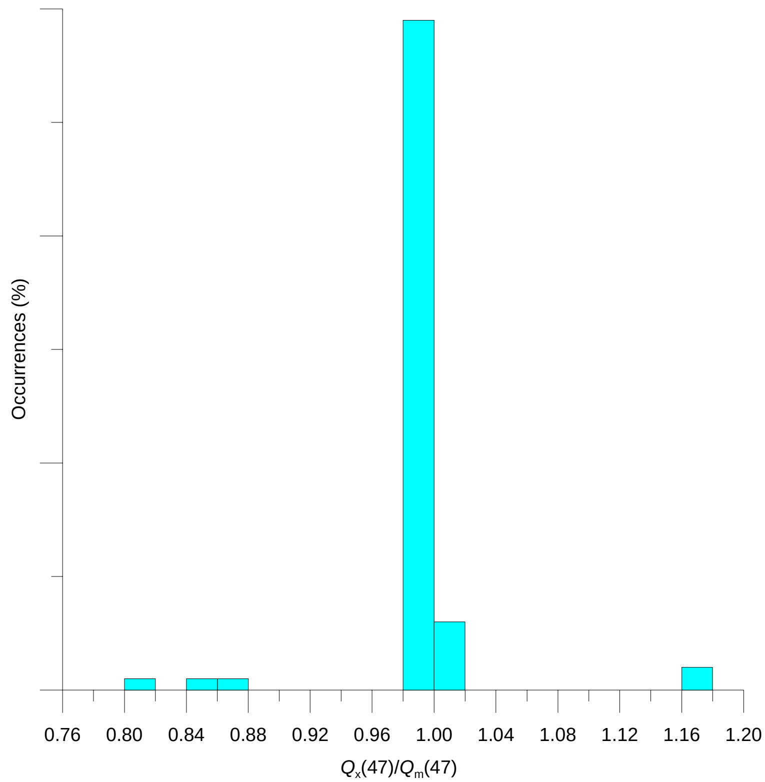

Figure 8: ICM H coil-only Q(47) ratio, $Q_x(47)/Q_m(47)$, distribution

Examining the ICM H mixed system with $Q_x(47)/Q_m(47)$ ratio of 1.16 showed that the OEM rated only the HSVTC system with this outdoor unit. Therefore the maximum $Q_x(47)/Q_m(47)$ ratio from the OEM was 1.0 for this outdoor unit and there were no other OEM mixed systems to compare to ICM H.

Heating Capacity Ratings for Coil-Blower Mixed Systems

Table 5 shows that ICM H, ICM J, and ICM K list 42.1 %, 36.0 %, and 68.4 % of their mixed systems higher than the matched HSVTC, respectively. These percentages are higher than the survey total of 3.1 % of coil-blower mixed systems with a higher heating capacity rating than the HSVTC. Examining Figures 11, 12, and 13 shows that only ICM H has a mixed system coil-blower heating capacity ratio greater than the calculated maximum of 1.05.

If we use the ARI database to examine the outdoor unit used by ICM H which was given a $Q_x(47)/Q_m(47)$ ratio of 1.06, the OEM rated seven systems with this outdoor unit and gave a maximum $Q_x(47)/Q_m(47)$ ratio of 1.05.

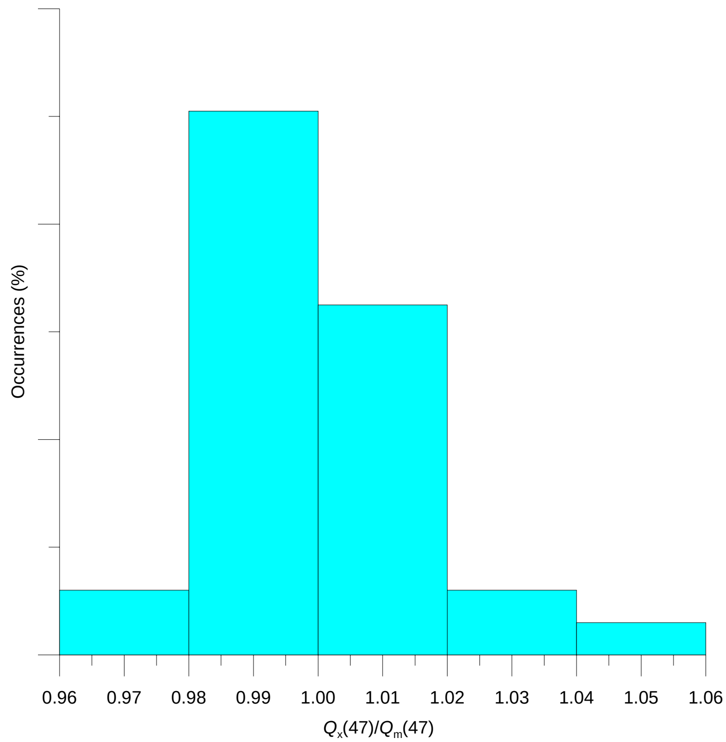

Figure 9: ICM H coil-blower $Q_x(47)/Q_m(47)$ ratio distribution

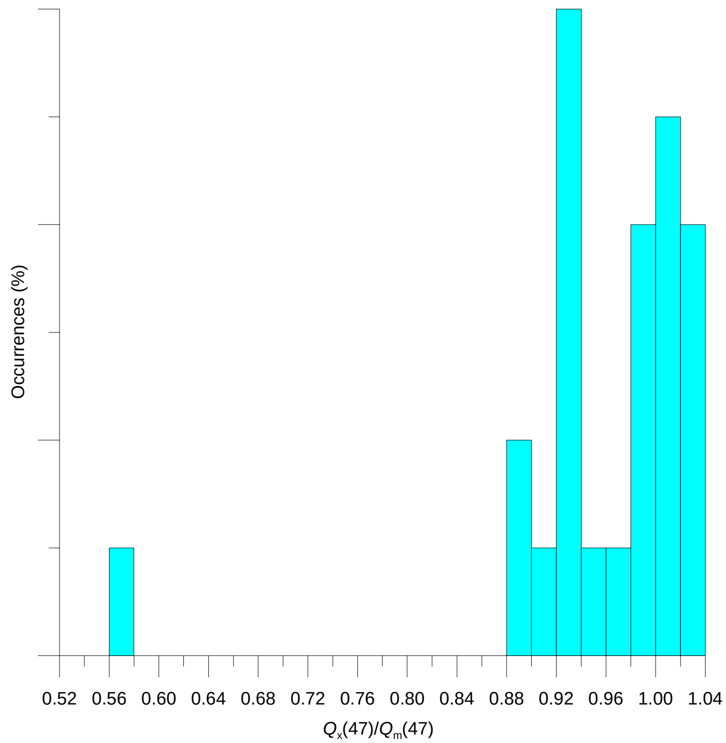

Figure 10: ICM J coil-blower $Q_x(47)/Q_m(47)$ ratio distribution

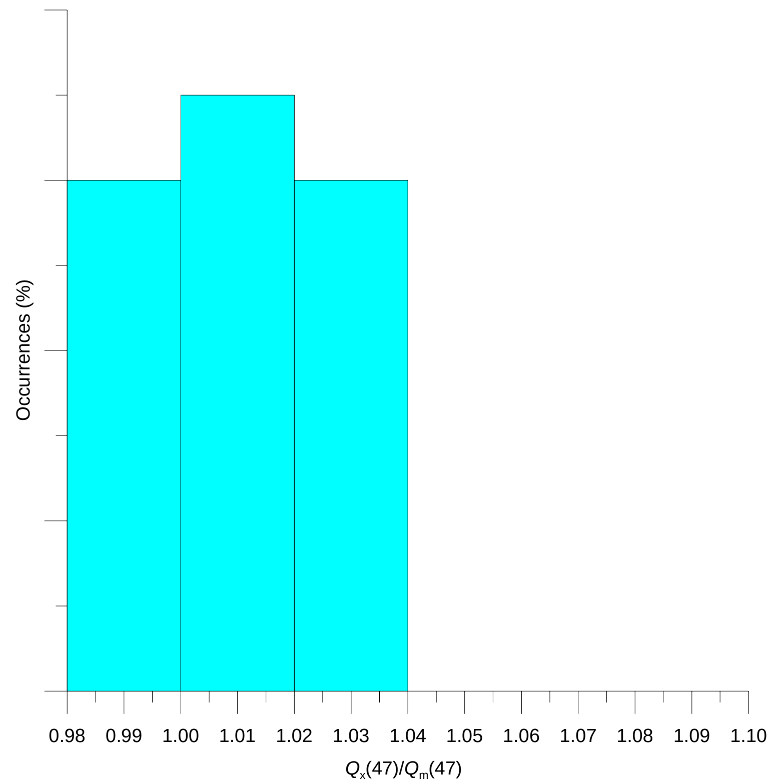

Figure 11: ICM K coil-blower $Q_x(47)/Q_m(47)$ ratio distribution

SIMULATION OF HSPF AND HEATING CAPACITY IMPROVEMENT USING ACSIM

An in-house air-conditioning system simulation software package, ACSIM, was used to determine the change in heating capacity and system power due to enhancing the performance of the indoor coil, i.e. increasing indoor coil area, increasing heat transfer coefficients, and decreasing refrigerant pressure drop. This software package combines EVAP-COND (NIST 2003), an evaporator and condenser modeling software package, with an expansion device and compressor model. Simulations were performed using an R410A example system. These simulations were used along with an HSPF calculation spreadsheet (Dougherty 2006) to show the variations in HSPF ratings possible with the enhanced indoor coil. No attempt was made to determine the cooling mode performance of the mixed systems.

The rated HSPF is calculated using the minimum design heating requirement in climate region IV. In general the rated HSPF is a function of 8 variables:

$$\mathrm{HSPF} = \mathrm{f}[\, Q(47), Q(35), Q(17), E(47), E(35), E(17), C_{\mathrm{d}}, F_{\mathrm{def}} \,] \qquad (7)$$

where $Q(35)$, $E(35)$ = heating capacity and power calculated during the frost accumulation test

$Q(17)$, $E(17)$ = heating capacity and power during the low temperature test

$E(47)$ = power used during the high temperature heating test

C_d = heating cyclic degradation coefficient
F_{def} = demand defrost credit multiplier.

Table 9: R410A system simulation and heating COP values from ACSIM

Indoor Airflow m^3/h (scfm)	Indoor HX Tube Length mm (in)	Total Capacity W (Btu/h)	Capacity ratio wrt base	T_{sat} Outdoor °C (°F)	Refrig. mass flow kg/h (lbm/h)	T_{sat} Indoor °C (°F)	Indoor Inlet Superheat °C (°F)	Air Temp at Indoor Exit °C (°F)	Total Power W	Power ratio wrt base	COP	COP ratio wrt base
Q(47) outdoor air conditions												
2370 (1395)	762 (30)	11516 (39294)	Base 1.0000	-1.7 (29.0)	187.5 (413.3)	35.8 (96.4)	25.6 (46.1)	34.9 (94.8)	2904	Base 1.0000	3.965	1.000
2379 (1400)	1016 (40)	11536 (39362)	1.0017	-1.7 (29.0)	187.5 (413.4)	35.1 (95.2)	25.3 (45.5)	34.8 (94.6)	2869	0.9879	4.020	1.014
2384 (1403)	1524 (60)	11543 (39388)	1.0024	-1.7 (29.0)	187.8 (414.1)	34.9 (94.8)	25.2 (45.4)	34.7 (94.5)	2860	0.9848	4.035	1.018
2387 (1405)	2032 (80)	11570 (39478)	1.0047	-1.7 (28.9)	187.6 (413.5)	34.6 (94.3)	25.2 (45.3)	34.1 (93.3)	2851	0.9817	4.057	1.023

where: T_{sat} Outdoor = evaporator exit refrigerant saturation temperature
T_{sat} Indoor = condenser inlet refrigerant saturation temperature
Scfm = air flow rate relative to standard air with a density of 1.2 kg/m^3 (0.075 lbm/ft^3)
Evaporator exit superheat set at 4.4 °C (8.0 °F) and condenser exit subcooling of 4.4 °C (8.0 °F)
Total capacity includes the fan heat (0.365 W/scfm)
wrt = with respect to

Table 9 shows the relative levels of change in capacity and power requirements with changes in the indoor coil heat transfer area. Even when the heat transfer area increased by 267 %, *Q*(47) heating capacity and system power changed by +0.5 % and -2.0 %, respectively. It can be reasonably expected that the percentage changes seen in the simulation cases would extrapolate to the *Q*(35) and *Q*(17) tests.

Using the ACSIM determined heating capacity (Table 9, Column 4) and power ratios (Table 9, Column 11), example system data were obtained for three matched systems (Dougherty 2006) with the capacity and power varied by the same percentages seen with the simulations. Table 10 shows the resulting changes in HSPF for these example systems when using the same percentage of change in heating capacity and power seen in Table 9.

Table 10: HSPF variation with fixed changes in heating capacities and powers

Capacity and Power Multiplier	Q(47) W, Btu/h	Q(35) W, Btu/h	Q(17) W, Btu/h	E(47) W	E(35) W	E(17) W	Heating C_d	F_{def}	HSPF	HSPF ratio, $HSPF_x/HSPF_m$
System 1										
1.000, 1.000	8951 (30542)	5968 (20364)	6099 (20809)	2454	2179	2090	0.25	1.00	8.64	1.000
1.005, 0.980	8996 (30695)	5998 (20466)	6129 (20913)	2405	2135	2048	0.25	1.00	8.85	1.024
1.010, 0.960	9040 (30847)	6028 (20568)	6159 (21017)	2356	2092	2006	0.25	1.00	9.07	1.050
System 2										
1.000, 1.000	9733 (33211)	9004 (30722)	5436 (18549)	2752	2521	2194	0.25	1.026	8.96	1.000
1.005, 0.980	9782 (33377)	9049 (30876)	5463 (18642)	2697	2471	2150	0.25	1.026	9.16	1.022
1.010, 0.960	9830 (33543)	9094 (31029)	5490 (18734)	2642	2420	2106	0.25	1.026	9.36	1.045
System 3										
1.000, 1.000	8499 (29000)	6301 (21500)	5129 (17500)	2000	1900	1800	0.15	1.02	9.86	1.000
1.005, 0.980	8542 (29145)	6333 (21608)	5155 (17588)	1960	1862	1764	0.15	1.02	10.09	1.023
1.010, 0.960	8584 (29290)	6364 (21715)	5180 (17675)	1920	1824	1728	0.15	1.02	10.33	1.048

The 1 % increase in heating capacity in addition to the 4 % decrease in total power, increases steady-state heating coefficient of performance (COP) by approximately 5 %, as shown in Table 10 within the highlighted rows. This increase in efficiency translated into a comparable 5 % increase in rated HSPF. These calculations assumed that heating cyclic degradation coefficient and demand defrost credit were constant for the three example systems. It appears that the maximum calculated HSPF of 8 % may be difficult to achieve just by modifying the indoor heat exchanger.

System 3 had the lowest heating cyclic degradation coefficient and a demand defrost credit multiplier of 1.02. Increasing the defrost credit multiplier is normally a difficult task that may add significant cost to a production heat pump. Therefore, the calculated maximum increase in HSPF of 8 % is still a good estimate of the maximum effect that heat exchanger size and system modifications have on HSPF.

SUMMARY AND DISCUSSION

All of the ICMs with active mixed systems that are listed in the ARI directory of certified unitary heat pumps and heat pump coils were considered in this survey of Q(47) and HSPF ratings. Only active status mixed systems with the same ARI-type indoor unit were compared. All ICM mixed systems used in the comparison had an ARI Status of “Active” as of November 2006.

All mixed systems were sorted into three categories; HSPF and *Q*(47) ratings 1) higher, 2) equal, and 3) lower than the OEM's HSVTC. These three categories were tabulated and a percentage value was calculated for each category for coil-only and coil-blower indoor unit types. The HSPF totals showed that 10.1 % and 6.3 % of mixed systems are rated higher, 48.4 % and 9.2 % are rated equal, and 41.5 % and 84.5 % are rated lower than the OEM HSVTC for coil-only and coil-blower indoor unit types, respectively. The Q(47) totals showed that 1.4 % and 3.1 % of mixed systems are rated higher, 23.6 % and 4.1 % are rated equal, and 74.9 % and 92.8 % are rated lower than the OEM HSVTC for coil-only and coil-blower indoor unit types, respectively.

Expansion and simplification of Domanski's (1990) correlations for mix-match heating capacity and HSPF ratios in addition to data from the ARI database showed that coil-only systems could have a maximum *Q*(47) heating capacity and HSPF ratio of 1.05 and 1.08, respectively. For those ICMs that exceeded these maximum calculated ratios, several of the OEM mixed systems that utilized the same outdoor unit were examined, and the ICM and OEM mixed system ratios were compared. The OEM mixed systems have heating capacity and HSPF ratios less than 1.06. This is within the bounds calculated.

A NIST in-house system simulation model, ACSIM, was used to determine the *Q*(47) heating capacity and efficiency gains possible by increasing the size of the indoor heat exchanger (condenser) for an already highly efficient system. The simulations showed that heating capacity only increased slightly with an increase in the indoor heat exchanger size. Heating COP increased by approximately 2 % with a 267 % increase in heat exchanger size.

HSPF was examined for three example systems by changing capacity and power by the same percentages as seen with the ACSIM modeled R410A system. HSPF was calculated for these mixed systems; even when the change in capacity and power were favorably adjusted by twice the amount seen during the simulations, the maximum increase in HSPF was only 5 %.

ICMs that tend to rate their mixed system higher than the OEM HSVTC represent a small percentage of the total number of ICM mixed systems. For this survey of 8196 coil-only and coil-blower mixed systems, 538 units, or less than 7 % of the units, surveyed had HSPF and Q(47) ratings higher than the OEM HSVTC. In comparison, ICMs published cooling mode SEER ratings higher than the OEM HSVTC for 13 204 mixed systems, or 40.3 % of all mixed systems (Payne 2006).

ACKNOWLEDGMENTS

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